Research on Bluff Body Vortex Wakes

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LONG-TERM GOAL

This combined experimental-computational research addresses the problem of flow-induced forces on vortex-shedding bluff bodies. The long-term goals are to:

- Improve understanding of the relation between the unsteady forces and vorticity histories in the near wake.
- Use new results and insights to assess existing models for flow-induced unsteady forces and to seek alternative models.

OBJECTIVES

Immediate objectives are to obtain experimental and computational descriptions of velocity and vorticity fields in the near wakes of vortex-shedding bodies and the corresponding forces on the bodies for the cases of (1) stationary bodies, (2) bodies in forced oscillation, and (3) freely oscillating bodies.

APPROACH

Numerical simulations are often employed to duplicate laboratory conditions, parameters, and for direct comparison. We emphasize their complementary role, taking advantage of capabilities not available in laboratory simulations. For example, purely two-dimensional flows and limiting cases such as cylinders of zero mass can be simulated to incorporate theoretical ideas. Such idealized results help find rational explanations for real-world results that are different from ideal, limiting behavior. Our numerical simulations are based mainly on vortex methods because of their efficiency for this class of flows.

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Our laboratory experiments are at high Reynolds number, where limiting values of structural parameters (e.g., zero mass) can of course not be achieved, and the flows are not two-dimensional. Experience shows useful correspondences between flows with $10^3 < Re < 10^4$ and those at about $Re=10^2$; these can be exploited for insights into the flow dynamics, which depend mainly on the large vortex formation and shedding processes.

WORK COMPLETED

Two completed numerical investigations are reported in the thesis by D. Shiels [1998]. In the first of these, an elastically supported cylinder is constrained to move only normal to the flow direction. Various combinations of the parameters (mass *m*, spring force *k*, damping b) were used, including zero values. In the second, the circular cylinder was given prescribed rotational oscillations around its center.

Two laboratory investigations were completed. In water-tunnel experiments on a circular cylinder, time histories of the transverse motion were obtained for a range of values of the mass-ratio and spring-force parameters. Amplitude and frequency response were analyzed. A second set of experiments on impulsively started cylinders used DPIV to measure the growth of circulation with time in the wake of the cylinder. The results are being written up for publication.

RESULTS

The numerical simulations at limiting parameters show that the lock-in does not describe the full behavior of the system. The computations also suggest that the response in undamped systems can be well-defined by a single lumped parameter termed the "effective stiffness" which combines the mass and spring terms by interpreting the inertial force as an anti-restoring force. This parameter collapses responses in the current study far more effectively than the traditional parameter, the reduced velocity. This has been confirmed for the experimental results, which show that a range $0< k^*_{eff} <5$ is required for large vortex induced vibration (VIV) amplitude. The new results suggest that significant flow induced vibration requires a synchronization between admissible states of the wake and motions possible under the mechanical constraints. The effects of damping on system response and the "effective stiffness" scaling were also investigated. More study is needed to test the new scaling ideas on other Reynolds numbers, a wider range of mechanical parameters, and with damping. Preliminary experiments on the effects of a second degree of vibration, inline with the freestream, have been also started.

A second set of simulations, on flow over a circular cylinder executing rotational oscillation, verified drag reduction observed experimentally by Tokumaru & Dimotakis [1991]. The results show a clear correlation between delay in separation and the drag reduction. Study of the flow evolution revealed that the bursting of multipole vorticity structures from the boundary layer dictates the wake development for low-drag cases. It was shown that this critical phenomenon was linked to the generation of a free shear layer type of instability near the boundary layer, caused by the oscillatory motion of the body.

From the experiments on impulsively started cylinders it was found that the "formation number" [Gharib & Rambod, 1998] which describes the formation of a vortex has the value "four diameters."

IMPACT/APPLICATION

Our several, interrelated approaches are revealing new views of vortex induced vibration (VIV). The numerical simulations show that the concept of "lock-in" is by no means sufficient for describing vortex induced vibration of a circular cylinder. This is confirmed by the experimental investigations, which show large parametric ranges in which the cylinder motion is controlled by the vortex-shedding wake. The concept of "effective stiffness," k^*_{eff}, reduces the number of parameters and may be more appropriate than "reduced velocity" for characterizing the response. The "formation number" measured in the impulsive cylinder experiments extends the applicability of this concept to the cylinder flows and may be helpful for modeling the vortex-shedding wake.

REFERENCES

M.R. Gharib, D. Shiels, M. Gharib, A. Leonard, and A. Roshko, 1998: "The absence of lock-in and the role of mass-ratio," ASME 5th International Symposium on Fluid-Structure Interaction, Aeroelasticity, Flow-Induced Vibration, and Noise, Washington DC.

M.R. Gharib, D. Shiels, M. Gharib, A. Leonard, and A. Roshko, 1998: "Exploration of flow-induced vibration at low mass and damping," submitted to *Journal of Fluids and Structures*.

F. Noca, D. Shiels, D. Jeon, "Measuring instantaneous fluid dynamic forces on bodies using only velocity fields and their derivatives," *Journal of Fluids and Structures*, **11**, 1997, 345-350.

F. Noca, D. Shiels, D. Jeon, 1998: "Measuring instantaneous fluid dynamic forces on bodies using only velocity fields and their derivatives (continued)," submitted to the *Journal of Fluids and Structures*.

F. Noca, H.G. Park, and M. Gharib, 1998: "Vortex formation length of a circular cylinder (300<Re<4000) using DPIV," ASME 5th International Symposium on Fluid-Structure Interaction, Aeroelasticity, Flow-Induced Vibration, and Noise, Washington DC.

D. Shiels, 1998: "Simulation of controlled bluff body flow with a viscous vortex method," Ph.D. thesis, California Institute of Technology.

F. Noca, 1997: "On the evaluation of time-dependent fluid-dynamic forces on bluff bodies," Ph.D. thesis, California Institute of Technology.

D. Shiels, A. Leonard, A. Roshko, 1998: "Flow induced vibration of a circular cylinder at limiting parameters," submitted to the *Journal of Fluids and Structures*.

D. Shiels, A. Leonard, 1998: "Investigation of drag reduction on a circular cylinder in rotary oscillation," submitted to the *Journal of Fluid Mechanics*.

P.T. Tokumaru and P.E. Dimotakis, 1991: "Rotary oscillation control of a cylinder wake," **24**, 77-90.

PUBLICATIONS

Gharib, M.R., Shiels, D., Gharib, M., Leonard, A., and Roshko, Al, 1998: “The absence of lock-in and the role of mass-ratio,” ASME 5th International Symposium on Fluid-Structure Interaction, Aeroelasticity, Flow-Induced Vibration, and Noise, Washington DC.

Noca, F., Shiels, D., Jeon, D., 1998: “Measuring instantaneous fluid dynamic forces on bodies using only velocity fields and their derivatives (continued),” submitted to the *Journal of Fluids and Structures*.

Shiels, D., Leonard, A., Roshko, A., 1998: “Flow induced vibration of a circular cylinder at limiting parameters,” submitted to the *Journal of Fluids and Structures*.

Shiels, D., Leonard, A., 1998: “Investigation of drag reduction on a circular cylinder in rotary oscillation,” submitted to the *Journal of Fluid Mechanics*.